LOW-NOISE SYSTEMS

Cryogenic HEMTs

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Exploring planets on the fringes of our solar system requires extraordinarily sensitive receive systems for the spacecraft-to-earth telecommunications link. Since the spacecraft transmitted power is limited and fixed, the communications burden is placed on the ground-based receivers, which must detect an extremely weak signal in the presence of a nearly overwhelming amount of noise. To achieve these sensitivities, as much as is physically possible of the input and output radio frequency communication components is cooled below ambient. Cryogenic cooling to temperatures between the boiling points of liquid hydrogen (22 K) and helium (4.2 K) significantly reduces the principal source of noise (thermal noise).

HEMTs are less expensive and simpler to maintain and operate than masers

Historically, the Jet Propulsion Laboratory's (JPL) Deep Space Network (DSN) has relied on ruby masers (cooled to 4.6 K) as the low-noise preamplifier for these ground-based systems. Currently, the DSN is developing and gradually implementing cryogenically cooled low-noise preamplifiers (LNAs), using high electron mobility transistors (HEMTs). These HEMT-based systems are extremely competitive with masers and have the added benefit of being less expensive (one-third the cost) and much simpler to maintain and operate (one-eighth the maintenance and operation cost) than masers.

A field effect transistor (FET) or HEMT can be viewed as a simple circuit that consists of three terminals—a source, drain, and gate. The amount of current flowing from the source to the drain is controlled by a voltage applied to the gate terminal. For digital applications the gate simply turns the current on or off, while in the analog (microwave) application a weak signal applied to the gate modulates the source to drain current, resulting in an amplified signal.

In order to understand the low noise properties of HEMTs one must examine the device's material structure. Below the gate in the active region of the HEMT is a two-dimensional conducting region sandwiched between precisely engineered layers of semiconductors. The layers, varying in thickness from one to several thousand atomic planes, are grown using a technique called molecular beam epitaxy. First, to block impurities from diffusing into the active region, a thick buffer Gallium Arsenide (GaAs) layer is grown on a semi-insulating GaAs wafer. Next, a spacer layer of Aluminum Gallium Arsenide (AlGaAs) approximately 10-atomic-planes thick is grown. Then, an AlGaAs layer 80 planes thick doped with silicon atoms is grown. The Si atoms donate conduction electrons and the spacer layer reduces donor ion/conduction electron interactions. Finally, a heavily doped AlGaAs layer 90 planes thick is grown to provide an electrical contact to the conduction electrons. This layered structure produces an electron energy minimum at the undoped AlGaAs/GaAs interface. Electrons from the Si doped AlGaAs layer are attracted to and collect at this interface forming a two-dimensional electron gas. In the GaAS FET structure, on the other hand, the donor region is grown along with the GaAs conduction electron region resulting in a three-dimensional conduction of electron gas. A schematic cross section for a GaAs HEMT and FET is shown in Figure 1.

Although the HEMTs and FETs share many similarities, it is this underlying two-dimensional structure of the HEMT that results in its superior noise performance. The primary advantage of this layered structure is that, unlike the heavily doped conduction region of the conventional GaAs FET, there are significantly fewer impurities in the undoped GaAs region of the HEMT where the two-dimensional electron gas resides. Thus, electrons in a HEMT experience fewer scattering events and travel at higher velocities than in conventional FETs, resulting in a significantly lower noise and higher gain device. (This is comparable to removing debris from the freeway.) In addition, cryogenic cooling can provide up to a tenfold improvement over noise performance at room temperature.

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Over the last two decades, considerable industrial research has been conducted on room temperature FETs and HEMTs for military applications. A significant portion of this research concentrated on optimization of super-low noise HEMTs for microwave and millimeter wave amplifiers. Device manufacturers handily met or exceeded their defense related sponsor's goals. In fact, some of these devices tested by the DSN Technology Program at cryogenic temperatures yielded exceptionally low noise results.

Although device noise temperatures continue to drop at room temperature, there is no guarantee that the same improvements will occur at cryogenic temperatures. A systematic and detailed investigation of the dc and microwave properties of advanced HEMT devices is required for the identification of the optimum HEMT structure for cryogenic low noise performance.

Through a collaborative effort with industry and academia, the DSN Technology Program is investigating alternate materials like Indium Gallium Arsenide and Indium Phosphide to further improve HEMT device performance. Additional device enhancements currently being investigated are shorter gate lengths to further reduce scattering events, and alternate doping strategies for stronger electron confinement to the two-dimensional gas region, such as planar doping (i.e., confining the Si donors to an atomic plane). In this program, TRW is responsible for iteratively improving device fabrication techniques, while JPL and the Georgia Institute of Technology are responsible for evaluating the devices at cryogenic temperatures. Our program goal is to meet or exceed maser performance by 1997.

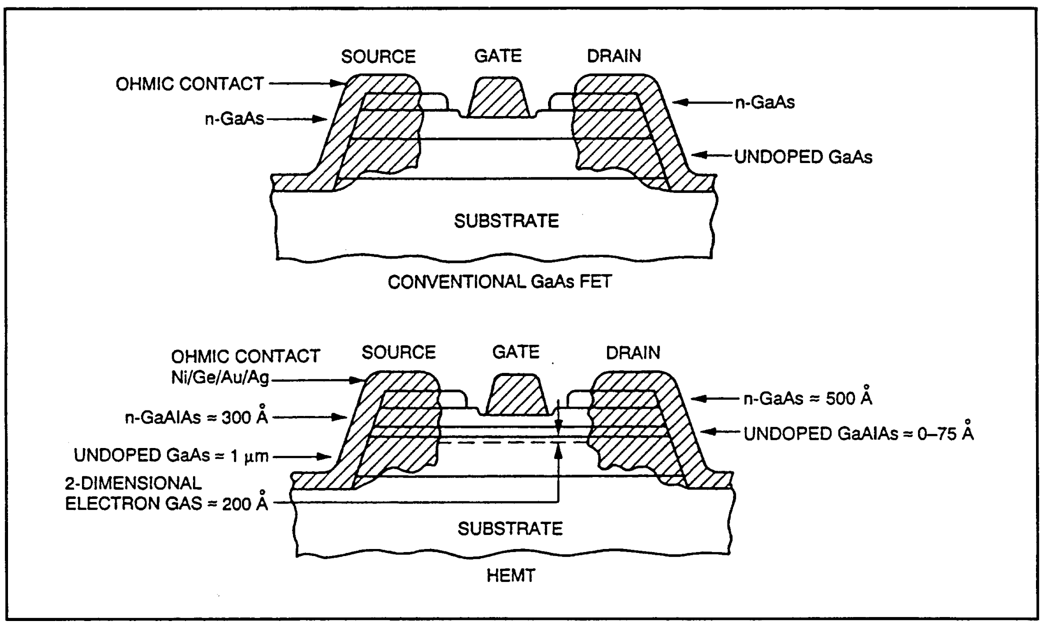

FIGURE 1. REPRESENTATION OF FET AND HEMT DEVICE CROSS-SECTIONS.

DIPLEXING CONTINUED FROM PAGE 5

TABLE 1. THE RESULTS OF A DIPLEXING EXPERIMENT DONE AT DSS 13 USING A FREQUENCY SELECTIVE SURFACE AS THE DIPLEXER

DSS 13 HEMT: Waveguide Diplexer	DSS 13 HEMT: FSS Diplexer	DSS 24 Maser: Waveguide Diplexer	Predicted Best Maser: Waveguide Diplexer
42 K	27.2 K	29 K	27.5 K

This diplexer is a quasi-optical frequency selective surface (FSS) that splits the received and transmitted signals and provides the isolation required between the signals. It can be removed mechanically during one-way receive only mode and thus requires only one LNA, as opposed to the scheme shown in Figure 1. This system eliminates the switch and diplexer parts of the current diplexing scheme. Since the switch and diplexer are not present, the entire set of receive components can be cryogenically cooled along with the LNA and further reduce the noise temperature of both the one-way and two-way modes.

The FSS, developed by Jackie Chen, consists of a flat plate that has been perforated by a set of rectangular holes. When this plate is placed in the path of the received 8.4-GHz signal, as the energy is being focused, it is transparent and allows the signal to pass directly to a receive feed. On the other hand, a 7.2-GHz signal originating in the 20 kW transmitter system and feed is reflected by the same plate into space. This configuration is shown in Figure 2.

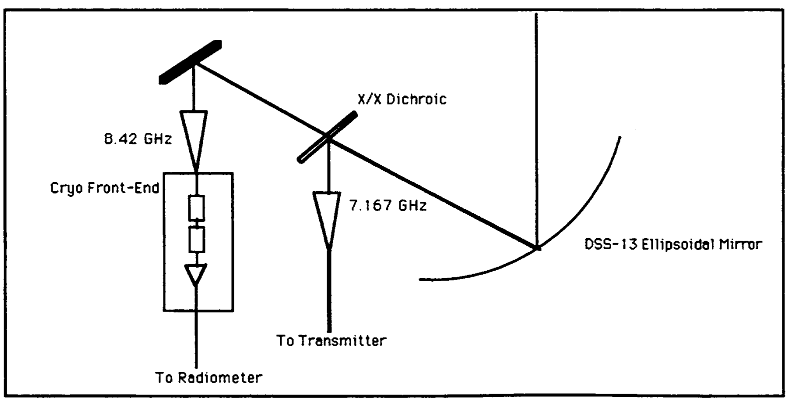

FIGURE 2. THE OPTICS CONFIGURATION THAT USES A FREQUENCY SELECTIVE SURFACE (FSS) AS THE DIPLEXER

A demonstration of this concept was recently carried out by Mike Britcliffe, Manuel Franco, Reg Cormier, and the DSS 13 Venus Station Personnel at DSS 13. An optics configuration was developed by Paula Lee and an FSS was fabricated to operate at the DSN X-band uplink and downlink frequencies. A receive-only feed system was built by Jim Bowen using a high electron mobility transistor (HEMT) LNA. All of the waveguide and LNA components were cryogenically cooled. A transmitting feed system was then connected to a 20 kW transmitter. The system was then operated in two-way mode and the total noise temperature of the receiving system was measured. The results of the demonstration were extremely valuable in showing that the concept is not only sound, but that it actually improves the performance of the receive system in *both* the one-way and two-way modes.

The R&D FSS diplexer has been successfully demonstrated to provide a benchmark for improved system performance relative to the present DSN waveguide diplexer concept and system design. There will soon be detailed reporting on the results of the DSS 13 demonstration in a TDA Progress Report. Furthermore, this configuration is presently being investigated for future operational DSN Beam Waveguide Antenna receiving systems.

Stay tuned for more unique ways of making quasi-optical microwave designs work for the DSN.

The *DSN Technology Program News* is a quarterly publication of JPL's Telecommunications and Mission Operations Directorate. The DSN Technology Program is managed by Dr. Chad Edwards.

Managing Editor .... Dr. Laif Swanson
Associate Editor .... George E. Shultz
Design and Layout .... Robin Dumas

JPL

Jet Propulsion Laboratory
California Institute of Technology

JPL D-12378 December 1995